BLAKESLEE & ENGER

An Experimental Study of Iron Removal from the Champaign and Urbana Water Supply

Municipal and Sanitary Engineering

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AN EXPERIMENTAL STUDY OF IRON REMOVAL FROM THE CHAMPAIGN AND URBANA WATER SUPPLY

BY

ELMER FREDERICK BLAKESLEE
AND
ARTHUR LUDWIG ENGER

THESIS

FOR THE

DEGREE OF

BACHELOR OF SCIENCE

IN

MUNICIPAL AND SANITARY ENGINEERING

IN THE

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1911

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UNIVERSITY OF ILLINOIS

June 1, 1911.

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ARTHUR LUDWIG ENGER and ELMER FREDERICK BLAKESLEE

ENTITLED AN EXPERIMENTAL STUDY OF IRON REMOVAL FROM THE CHAMPAIGN AND URBANA WATER SUPPLY

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Municipal and Sanitary Engineering.

A N Talbot
Instructor in Charge

APPROVED: A N Talbot

HEAD OF DEPARTMENT OF Municipal and Sanitary Engineering.

Introduction.

The water supply of Champaign and Urbana comes from wells about one hundred sixty feet deep in glacial drift. The water from these wells contains a considerable amount of organic matter, very little, if any, oxygen, and about two parts per million of iron in solution as ferrous carbonate. Upon coming in contact with air the iron is oxidized and is precipitated. Considerable time is required for the iron to be entirely precipitated and a great deal of it deposits in the mains when the current is slow. When increased consumption causes a greater current, the mains are flushed out and the water flowing from the faucets is a dark brown color. Clothes washed in this water are stained a rusty brown and spoiled. In addition to these disagreeable features, the iron encourages the growth of a microscopic filamentous plant called crenothrix. In regard to crenothrix the Report for the years 1897-1902, Chemical Survey of the Waters of Illinois, states: "This organism is not especially deleterious to the health, but it brings about the separation of the iron from the water and its deposition as rust like ferric hydroxide in and upon its own filaments, the growths causing a marked turbidity of disagreeable appearance and producing unpleasant tastes and odors. Frequently it grows so luxuriantly in the distributing system as to clog the pipe with masses of

dirty greenish or brown colored, iron impregnated vegetation. At times, the growths becoming loosened from the pipes, cause the liquid flowing from faucets to have the appearance of a fluid mud of iron rust rather than that of water."

Mr. Allen Hazen in his "Filtration of Public Water Supplies" states that three tenths of a part per million of metallic iron will very rarely precipitate or cause any trouble, while five tenths of a part per million occasionally precipitates. Mr. Hazen considers five tenths of a part per million the allowable limit of iron in a satisfactory water. He says further that one part per million is quite sure to precipitate and give rise to complaint, while from two to three parts per million makes the water entirely unsuitable for laundry purposes.

As a result of the many disagreeable features of the iron the following provision was inserted in an ordinance providing for a supply of water to the City of Champaign, passed by the City Council April 19, 1910:- "The water supply shall be artesian water pumped from deep bored or driven wells, and shall be wholesome and suitable for domestic use. The Company shall within two years from the passage of this ordinance install and thereafter maintain such necessary filters or other apparatus at its pumping station for the purpose of removing at least fifty per cent (50%) of the iron and other sediment from the water before pumping the same into the mains, and said filters or other apparatus shall be kept in operation."

This thesis is an experimental study to determine a method which might be used by the Champaign and Urbana Water Company in compliance with the above ordinance.

General Theory and Available Data .

Mr. Allen Hazen in his book,"Filtration of Public Water Supplies", says:- "Natural sands, gravels and rocks almost always contain iron, often in considerable amount. The iron is usually combined with oxygen as ferric oxide, and in this condition it is insoluble in water. Water passing through iron containing materials will not ordinarily take up iron. When, however, the water contains a large amount of organic matter in solution, this organic matter takes part of the oxygen away from the iron, and reduces the ferric oxide to ferrous oxide. The ferrous oxide combines with carbonic acid, always present under these conditions, forming ferrous carbonate, which is soluble and goes into solution. --- It is thus only in the presence of organic matters, and in the absence of free oxygen, that the solution of iron is possible."

Water containing iron is found in a great many places, and a large number of iron removal plants have been built. In general, the method used is to aerate the well water by running it over steps, by allowing it to drip through pans, or by allowing it to percolate through coke towers. After aeration the iron is removed by filtration, either slow sand filtration with rather high rates, or rapid sand filtration.

Ferrous carbonate is oxidized and changed to

ferric hydrate by aeration. Ferric hydrate forms a flocculent precipitate and is readily removed by filtration. In some places a coagulant is used in addition to aeration, but this increases the cost of iron removal and is avoided whenever possible.

Among the first plants for the removal of iron were the filters constructed at Amsterdam and at The Hague in Holland. The water at both of these places is aerated by flowing through open canals, and the iron removed by ordinary slow sand filters. Both of these plants have given satisfactory results.

At Far Rockaway, L. I., the water is aerated by flowing out of the bell of a vertical sixteen inch pipe and falling through the air to a receiving basin. The iron is removed by open filters. All of the iron separates out on top of the sand. There is an algae growth in the water upon the filters, which, with the iron, forms a mat upon the surface of the filter. The filters are cleaned by rolling up this mat. These filters have operated for years without any decrease in efficiency and without any material decrease in the thickness of the sand bed.

W. G. Stromquist's Report.

During the summer of 1910, William Gottfrid Stromquist, B. S., ran a series of experiments at the pumping station of the Champaign and Urbana Water Company. The experimental plant which he built was the one used in the work on this thesis, and is described on page 12. Mr. Stromquist made eleven series of tests with different combinations of filters and also several miscellaneous tests.

On page 11 are curves showing the amount of aeration of the water in different parts of the aerator at rates of 33,000 gallons per day to 86,400 gallons per day. The increase in dissolved oxygen at rates of about 30,000 gallons per day is six parts per million. By running the water through the empty gravel filter boxes the amount of dissolved oxygen was further increased about two parts per million in one of the series of tests.

Two grades of gravel were used for tests of upward filtration through coarse material. The coarse gravel passed a two-mesh screen and was caught on a screen three meshes to the inch. The fine gravel passed a three-mesh screen and was caught on an eight-mesh screen. Mr. Stromquist's results for upward filtration through gravel indicate that the amount of iron removed varied nearly with the depth of gravel. At a rate of 150,000,000 gallons per acre per day his results indicate each foot of coarse gravel would remove about 0.3 parts per million of iron, or seven feet of gravel would remove all of the iron from the well water.

These results were obtained with depths of gravel of three feet or less, and the maximum per cent removal was about seventy seven. Mr. Stromquist did not recommend gravel filters in his report mainly because of the difficulty of washing them.

When the sand filter was first used it ran eighty two hours without washing, and removed all the iron supplied (0.9 parts per million). At the beginning of the first test the filter used up 1.8 parts per million of oxygen, leaving 6.3 parts per million in the effluent. At the end of the first test the oxygen taken from the water by the filter was 4.8 parts per million, and only 0.7 of a part per million of dissolved oxygen was left in the filtered water. The rate used for the first run was 140,000,000 gallons per acre per day. After the filter had been in operation for some time the amount of dissolved oxygen in the water remained near 1.0 part per million. The accompanying table gives a summary of Mr. Stromquist's tests of the sand filter.

These experiments show that only clean filtering material would completely remove the iron from the water. It seems that the rate at which the filter clogs depends more on the quantity of water passed through than upon the amount of iron removed. It is also evident that the amount of iron remaining in the effluent is nearly independent of the amount of iron in the water applied to the filter.

In his report, Mr. Stromquist states:- "After the filters had been in operation for some time, the final effluent contained some iron. This was thought to be due

to the growth of organisms upon the sand which took up the oxygen and interfered with the oxidation and precipitation of the iron. The sand was treated with a solution of hypochlorite of lime (bleaching powder) and thoroughly washed, and better results were obtained." Mr. Stromquist did not state during what series he used bleaching powder, but the improvement of the effluent in Series XI and the final runs A and B, indicate that the bleach was used before these tests were made.

Mr. Stromquist reached the following conclusions:

Aeration.-

The dissolved oxygen in the water should be increased to at least six or seven parts per million, aerators to be attached to discharge pipes of the deep well pumps and the aerated water pumped from the old reservoir on to the filters by a centrifugal pump.

Filtration.-

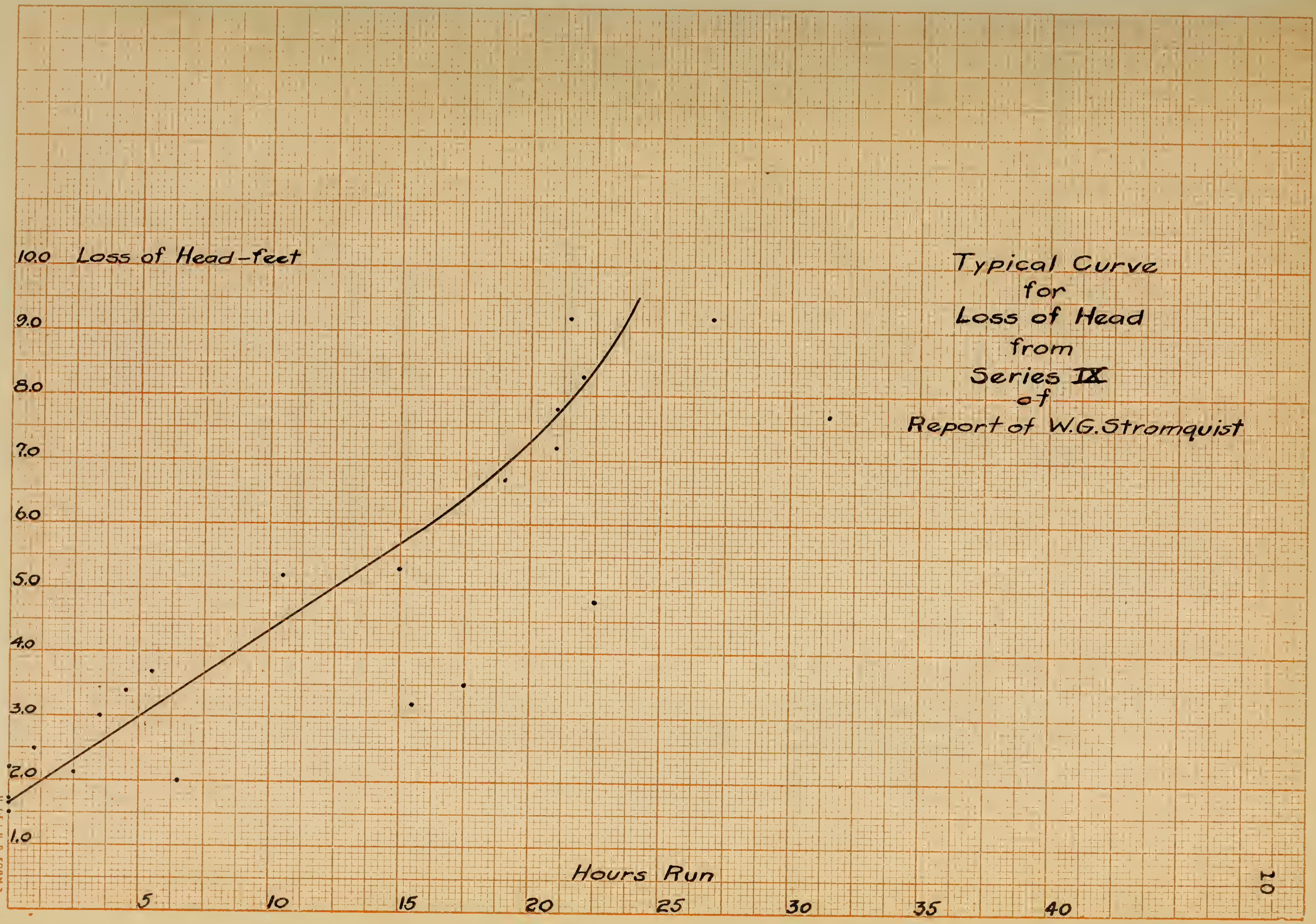
The water should be filtered through sand filters at a rate of one hundred twenty five million gallons per acre per day. The filter could be run twenty four hours between washings with a loss of head of seven feet. The filters should be occasionally treated with bleaching powder.

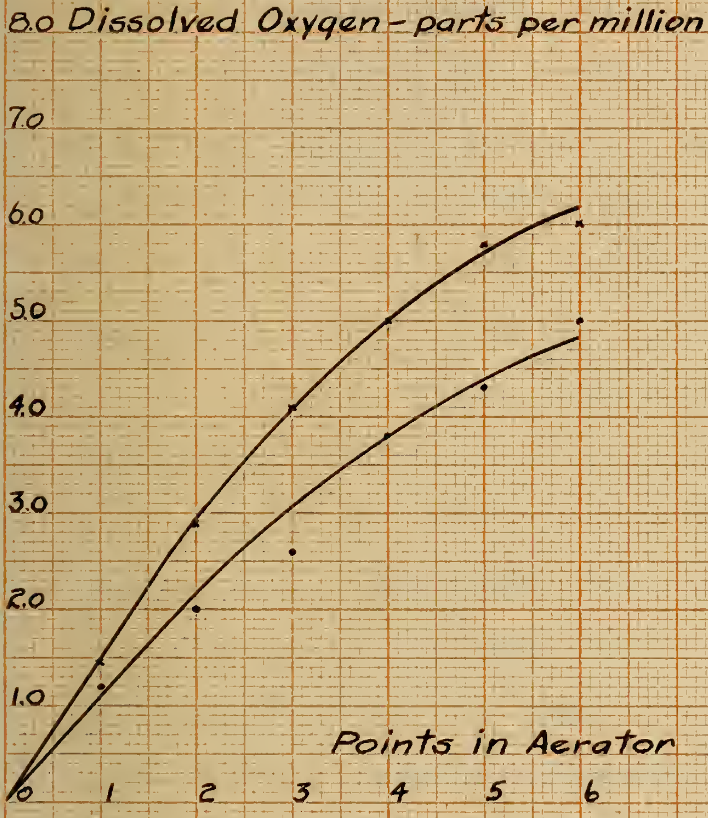
Tests of Sand Filter
from
Report of W.G. Stromquist

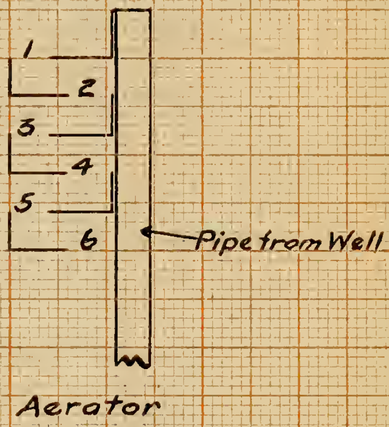
Iron and Dissolved Oxygen given in parts per million

Series Number	Rate of Filtration Gallons per acre per day	Depth of Sand Inches	Average Length of Time between Washings Hours	Water from Well (Aerated) Dissolved Oxygen p.p.m.	Water from Well (Aerated) Iron p.p.m.	Water from Effluent Dissolved Oxygen p.p.m.	Water from Effluent Iron p.p.m.
*I	140,000,000	27	69	5.7	0.9	3.0	0.0
*II	240,000,000	27	13	3.6	1.1	1.3	0.0
III	125,000,000	27	27	6.4	2.1	1.2	0.04
*IV	125,000,000	27	30.5	6.4	1.2	0.9	0.0
*V	130,000,000	15	25	6.8	1.4	1.4	0.06
*VI	125,000,000	15	26	5.2	1.1	1.3	0.3
VIII	98,000,000	15	34	9.1	2.0	2.2	0.7
IX	125,000,000	27	27	9.2	2.0	2.1	0.6
*X	125,000,000	27	27	5.1	1.1	1.0	0.5
XI	125,000,000	27	34	7.5	2.1	1.3	0.36
*A	125,000,000	27	50	5.9	0.9	1.1	0.26
B	125,000,000	27	42	7.7	2.1	1.5	0.3

* Water had received preliminary filtration thru gravel filters


10.0 Loss of Head-feet
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Typical Curve
for
Loss of Head
from
Series IX
of
Report of W.G.Stromquist
Hours Run
5
10
15
20
25
30
35
40





Dissolved Oxygen
at
Different Points in Aerator
from
Report of W.G. Stromquist

Apparatus and Methods.

The experimental filters used were those built by W. G. Stromquist for the Champaign and Urbana Water Company at their pumping station. The following description and sketch of plant is taken from the report of Mr. Stromquist to the Water Company: "An aerator was placed on a vertical pipe connected to the discharge pipe of Pump No. 1. By means of a valve all or a part of the water discharged by this pump could be turned to the filters.

"Three wooden tanks were arranged to give upward filtration thru gravel. The gravel was supported on screens six inches above the bottom of the filters. In this way uniform flow thruout the filter was secured. The water was admitted at the center of the bottom of the filter and after passing thru the sand it flowed over a weir on one side of the filter into a trough from which it was carried to the next filter. 2 1/2 inch pipe was used so that higher rates of filtration could be tried without too great loss thru friction. Valves were arranged so that any one or all of the filters could be omitted.

"A galvanized iron tank was used for the sand filter. In the bottom of this was a strainer system, the main pipe increasing successively from 1 1/4 to 1 1/2 inch, 2 inches and 2 1/2 inches, with 1 1/4 inch branch pipes which were tapped and fitted with Roberts Manufacturing Co. strainers. The branch pipes were placed 5 inches and the

strainers 4 inches center to center, a total of 48 strainers being used. The strainers were covered with 6 inches of gravel and the filter sand placed on top of the gravel. The inlet pipe was connected 4'-9" above the bottom of the filter, and four 2" outlets to carry off the wash water were connected 6'-0" above the bottom. A glass tube was connected above the sand and one on the effluent pipe. The difference in level of the water in these tubes gave the loss of head thru the filter.

"Each filter had an area of 8 1/3 square feet which gave a capacity of 25,000 gallons per day at the ordinary rate used in rapid sand filtration, 125,000,000 gallons per acre per day.

"For washing the sand filter a pipe for compressed air and one for wash water were connected to the effluent pipe. Air was admitted for a few minutes before the wash water was turned on in order to get the sediment well stirred up and loosened from the sand.

"To regulate the rate of filtration a small controller tank with a butterfly valve was used. A valve on the outlet pipe of this tank could be opened to give the desired rate and by means of a float on the butterfly valve a constant level of the water in the tank was maintained.

"The flow of the water was measured by means of submerged orifices 1 1/2" x 2". The water was measured by means of an orifice box immediately after passing thru the aerator, and again after going thru the sand filter. By this arrangement it was possible to operate the gravel filters

at a faster rate than the sand filter and get an approximation of the rate of filtration of each. The rate of flow was calculated from the difference in level of the water on each side of the orifice, using the formula for theoretical discharge with a coefficient of discharge of 0.60. -- The sand was 'Torpedo sand', using the part which passed an 8-mesh screen and was caught on a 12-mesh screen. This sand had an effective size of 0.76 millimeters, and a uniformity coefficient of 3.0. This is considerably coarser than ordinary filter sand. The 'Red Wing' filter sand in the experimental filter at the University of Illinois has an effective size of 0.43 millimeters, and a uniformity coefficient of 1.51"

During the later series of tests part of the original aerator was removed and a baffled trough placed between the aerator and filter. The inside dimensions of this trough were 5 3/4 inches wide, 4 inches deep and 19 1/2 feet long. The baffles were fastened to alternate sides of the trough and were placed eighteen inches center to center.

The test for iron was made as follows. Fifty cubic centimeters of the water were placed in a Nessler tube and one cubic centimeter of nitric acid was added. After this had stood for a short time, about one cubic centimeter of a solution of potassium sulpho-cyanide (20 grams per liter) was added. The amount of iron in the water was determined by comparing the color of the treated sample of water with a series of standards made up from

a solution of ferrous ammonium sulphate and treated in the same way as the sample of water. The standard iron solution contained 0.4 grams of ferrous ammonium sulphate per liter, or one cubic centimeter of the standard solution was equivalent to .0001 grams of Fe.

The test for dissolved oxygen was made according to directions in "Chemical Survey of the Waters of Illinois, Report for the years 1897-1902." The test as there given is as follows: "For the determination of dissolved oxygen, we have found the method of Albert Levy most satisfactory. The process involves the use of a special pipette with glass cock at each end. The capacity of the pipettes which we have used is exactly 107 cc. The reagents employed consist of a solution of 100 grams of caustic potash in a liter of water, a solution of 20 grams of ammonio ferrous sulphate in a liter of water, a fifty per cent solution of sulphuric acid, and a standard solution of potassium permanganate of such strength that one cubic centimeter is exactly equivalent to one tenth of a milligram of oxygen.

"The method of procedure is as follows: The pipettes are filled with the water either by immersing in the stream itself or by use of a rubber syringe. Then two cubic centimeters of the caustic alkali solution is put into the funnel at the top, and, by careful manipulation of the two cocks, is allowed to enter and mix with the water without admitting air. The funnel is then rinsed out and five cubic centimeters of the ammonio ferrous sulphate solution introduced into the funnel

and then into the pipette by the same manipulation as before. The water run out the pipette at the bottom as the reagents are admitted at the top is caught in the beaker in which the subsequent titration with permanganate is to be effected and which already contains two cubic centimeters of 50 per cent sulphuric acid.

"It is assumed that the alkali and iron solutions in entering the pipette displace their own volume of water, and with careful manipulation this undoubtedly is essentially effected, so that we may assume that within the pipette there remain one hundred cubic centimeters of the original water with seven cubic centimeters of the reagents.

"The mixing of the liquids within the pipette is effected by shaking the pipette with an eccentric rotatory motion. In the course of a few minutes the action is completed, and from the color of the precipitate one may gather an idea as to the relative amount of oxygen contained in the solution. That is, if the water is about saturated, the precipitate is apt to show a somewhat brownish color due to the ferric hydroxide, while if the quantity of oxygen is very small the precipitate is likely to be black, showing the preponderance of the ferrous hydroxide in the precipitate.

"After a few minutes, when the action is thought to be complete, five cubic centimeters of sulphuric acid are introduced into the funnel, and the cock between the funnel and the pipette being opened, the sulphuric acid, by reason of its greater gravity, passes from the funnel down into the interior, and mixing with the liquid dissolves the hydrox-

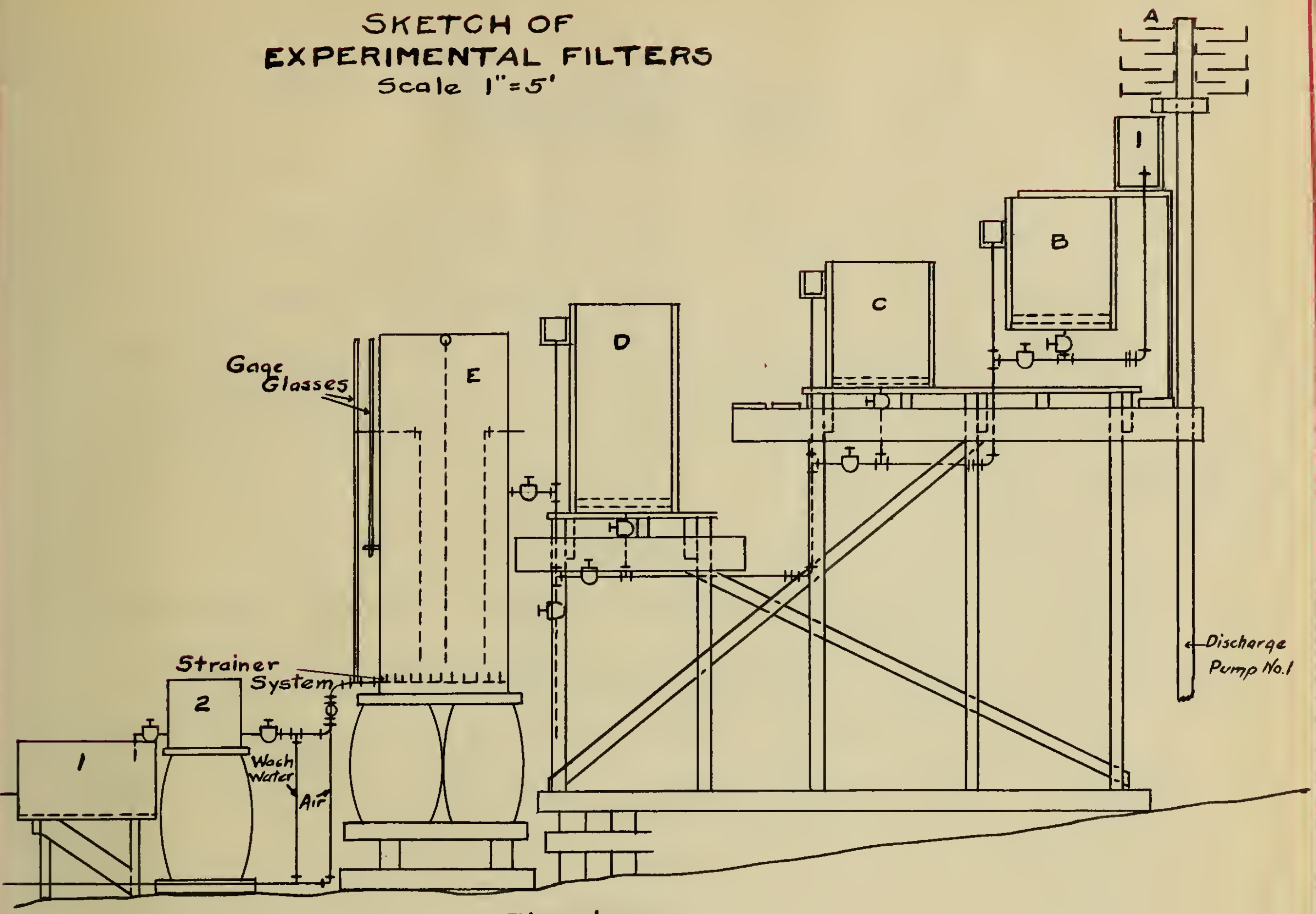
ides of iron and renders the entire liquid acid.

"When this reaction is complete, as shown by the clearing up of the solution, the contents of the pipette and the rinsing water are run into the beaker, and the excess of ferrous salt determined by titration with the standard permanganate solution. A blank is run upon one hundred and seven cubic centimeters of the original water for every determination that is made, this being easily done while the reactions are taking place within the pipette.

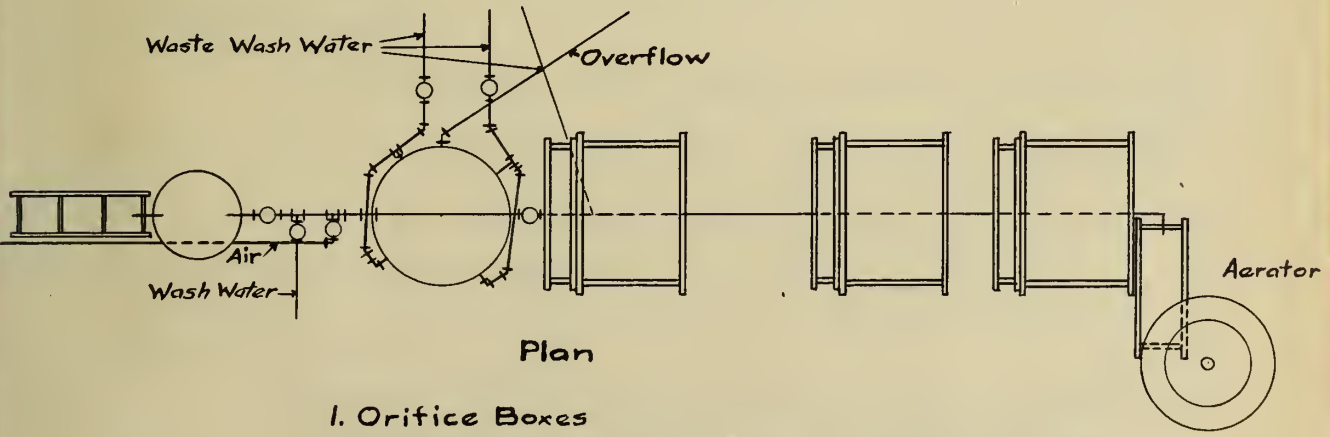
"In running the blank, one hundred and seven cubic centimeters of the water are measured into a beaker, then seven cubic centimeters of the sulphuric acid are added, and the liquid mixed; after this the caustic potash, two cubic centimeters is added, and finally, precisely five cubic centimeters of the ferrous sulphate solution; then the titration is effected as in the actual determination. The difference between the two readings, i.e., that of the blank and that of the direct determination, represents the quantity of dissolved oxygen in one hundred cubic centimeters of the water."

SKETCH OF EXPERIMENTAL FILTERS

Scale 1" = 5'



Elevation



Plan

1. Orifice Boxes
2. Controller tank - 2'-0" ϕ 21" deep with butterfly valve

B. and C. Gravel Filters - 30"×40", 3'-0" deep

D. Gravel Filter - 30"×40", 5'-0" deep

E. Sand Filter - 40" ϕ, 9'-0" deep

Pipe connecting filters - 2½"

Wash Water pipe - 1½"

Air pipe - ¾"

Waste Water pipes - 2"

Overflow pipe - 2"

Difference in elevation between B and C - 1.6'

Difference in elevation between C and D - 1.2'

Experimental Work.

The experimental plant was first used for work on this thesis February 22, 1911. The air pipe was not connected up, so the filter was washed with water alone. The quantity of water from the wash water pipe was not sufficient to stir up the sand to any extent. The discharge from the wash water pipe was 41,250 gallons per day or 205,125,000 gallons per acre per day, not quite twice the ordinary rate for rapid sand filtration. Twenty seven inches of sand was used in the filter "E". As the filter was never thoroughly washed the initial loss of head increased from one foot for the first run to four and a half feet for the fourth run. Practically complete removal of the iron was obtained.

After March 8, 1911 air was used in addition to the wash water. The sand was first stirred up with air and water, then the air was nearly shut off and the drain pipes opened. The initial loss of head varied from one and a half to two feet.

On April 13th a series of tests was run with the baffled trough in place of a part of the old aerator. After this series and a special test to determine the loss of head curve, all the sand was removed from the filter and the underdrains tested.

Gravel passing through a screen eight meshes to the inch was put in the filter and a test commenced which

had to be discontinued on account of trouble with the well.

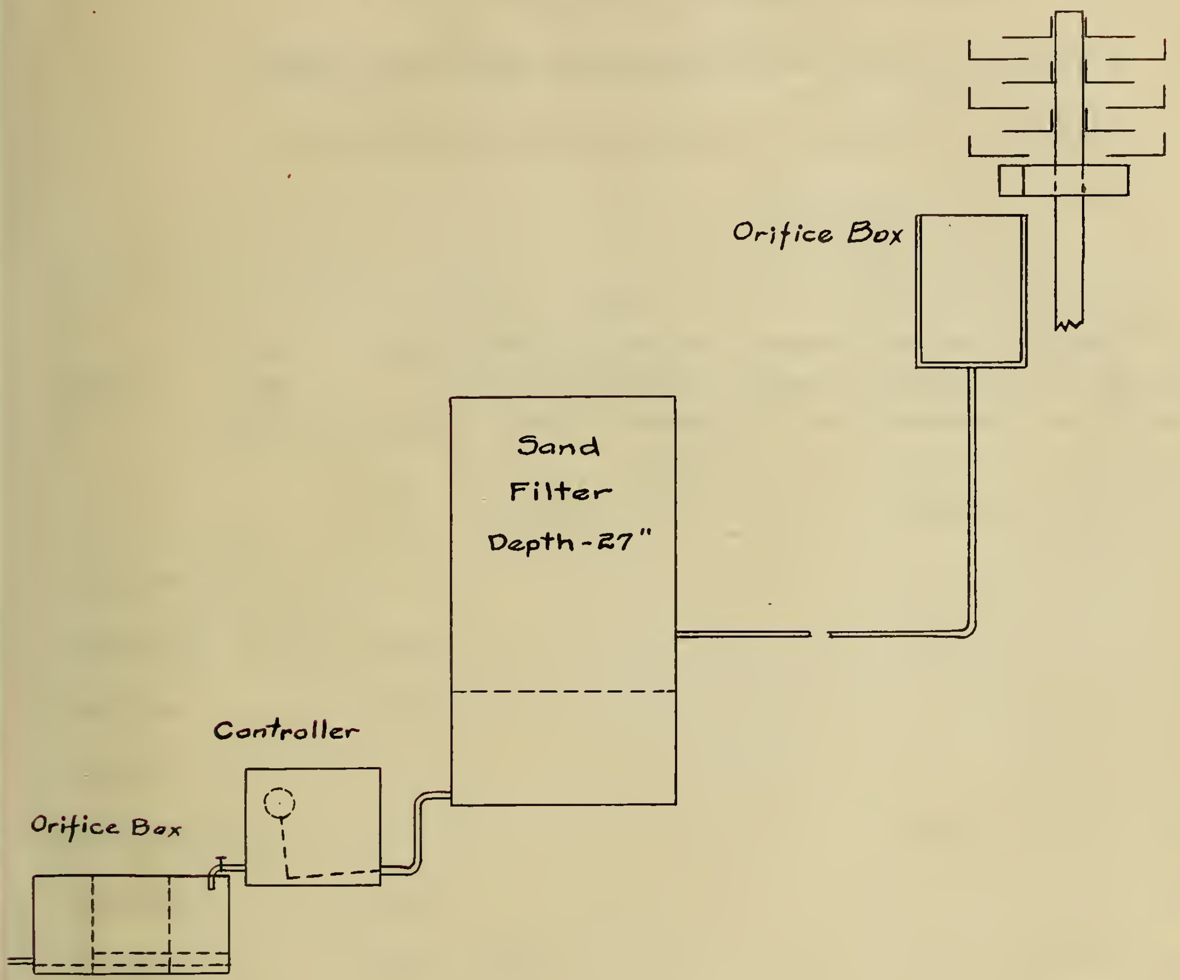
A centrifugal pump and electric motor were then set up in an effort to pump water directly from the old reservoir to the filter. A break in one of the walls of the reservoir made it necessary to empty it and various accidents delayed the refilling of the reservoir until it was too late to make any tests.

The experimental work was started late in the year on account of breakage of a valve, and the disconnecting of the wash-water and air pipes. After the experimental work was begun many tests had to be discontinued on account of the failure of the well supplying water to this filter. Well No. 1 is equipped with a belt driven, Luitwieler pump. The belt driving the pump ran through a tunnel and in very wet weather the pump was shut down on account of belt slippage. The well also became filled with sand several times, causing a shut-down until the sand could be removed. At times also, the water from this well contained as much as seven parts per million of dissolved oxygen, indicating that the level of the water in the well was drawn below the pump screens or else there was a leak in the suction pipe.

Series I

Filter Washed with Water Alone

Rate - 125,000,000 gallons per acre per day



Date	Hours after Washing	Loss of Head feet	Iron Parts per million	
			Influent	Effluent
Feb. 22, 1911	0	1.0	2.0	0.6
Feb. 23, 1911	29	4.0	—	—
Feb. 26, 1911	0	2.5	—	—
Feb. 27, 1911	0	4.0	—	—
Mar. 1, 1911	0	4.5	2.0	0.2

Series II

Filter Washed with Air and Water

Rate – 125,000,000 gallons per acre per day

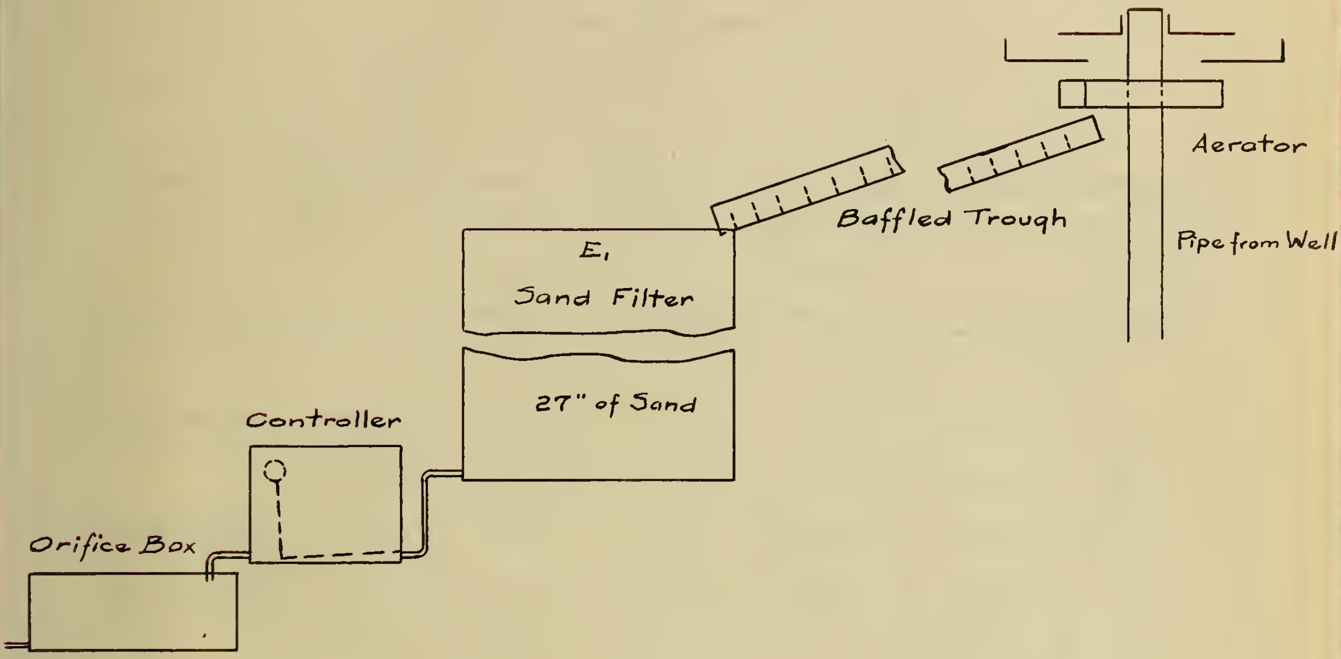
Iron and Dissolved Oxygen given in parts per million

Date	Hours after Washing	Lost Head ft.	A_1 Water direct from Well		E_1 Water above Sand in Filter		E_2 Water after Filtration	
			Iron p.p.m.	Dissolved Oxygen p.p.m.	Iron p.p.m.	Dissolved Oxygen p.p.m.	Iron p.p.m.	Dissolved Oxygen p.p.m.
Mar. 8, 1911	0	2.1	—	—	—	—	—	—
Mar. 9, 1911	24	8.0+	—	—	—	—	—	—
Mar. 9, 1911	0	1.5	—	—	—	—	—	—
Mar. 10, 1911	21	4.3	—	—	—	—	—	—
Mar. 11, 1911	—	—	—	—	—	6.1	—	2.8
Mar. 11, 1911	0	2.0	—	—	—	—	—	2.2
Mar. 25, 1911	22	3.6	2.0	1.2	2.0	7.5	0.0+	0.0
Apr. 1, 1911	25.5	4.4	—	—	—	—	—	—
Apr. 3, 1911	46	9.0+	—	—	—	—	0.0	1.9
Apr. 3, 1911	0	2.0	—	—	2.0	7.2	0.2	4.0

Series III

Filter Washed with Air and Water

Rate – 125,000,000 gallons per acre per day



Loss of Head

Date	Hours after Washing	Loss of Head feet	Remarks
Apr. 13, 1911	0	1.7	
	16	7.0	
	21	8.5 +	
Apr. 14, 1911	0	2.0	
	17.25	7.2	
	21.5	8.2	
Apr. 15, 1911	0	2.0	
Apr. 17, 1911	0	2.2	Washed with Bleaching Powder
	4	3.4	
	6.25	4.0	
	22.7	8.0 +	
Apr. 18, 1911	0	1.4	
	22.5	9.0	

SERIES III (continued)

Dissolved Oxygen and Iron

Date	A_1 Direct from Well		E_1 Above Sand in filter		E_2 Filtered Water	
	Iron p.p.m.	Dissolved Oxygen p.p.m.	Iron p.p.m.	Dissolved Oxygen p.p.m.	Iron p.p.m.	Dissolved Oxygen p.p.m.
Apr. 14, 1911	1.6	6.7	—	7.0	0.1	2.0
	1.6	6.5	—	7.5	0.0 +	3.5
Apr. 15, 1911	1.6	7.0	1.6	9.0	0.0 +	2.0
Apr. 17, 1911	1.6	7.2	1.6	7.4	0.5	2.0
	—	7.0	—	—	—	—
Apr. 18, 1911	0	8.0	1.8	10.0	0.5	3.5
	—	—	—	* 9.5	—	—

* Sample taken just above sand

E_1 and E_2 samples taken 10 inches below surface

A_1 sample taken with a siphon

Iron and dissolved oxygen given in parts per million

Special Test

to

Determine Loss of Head Curve.

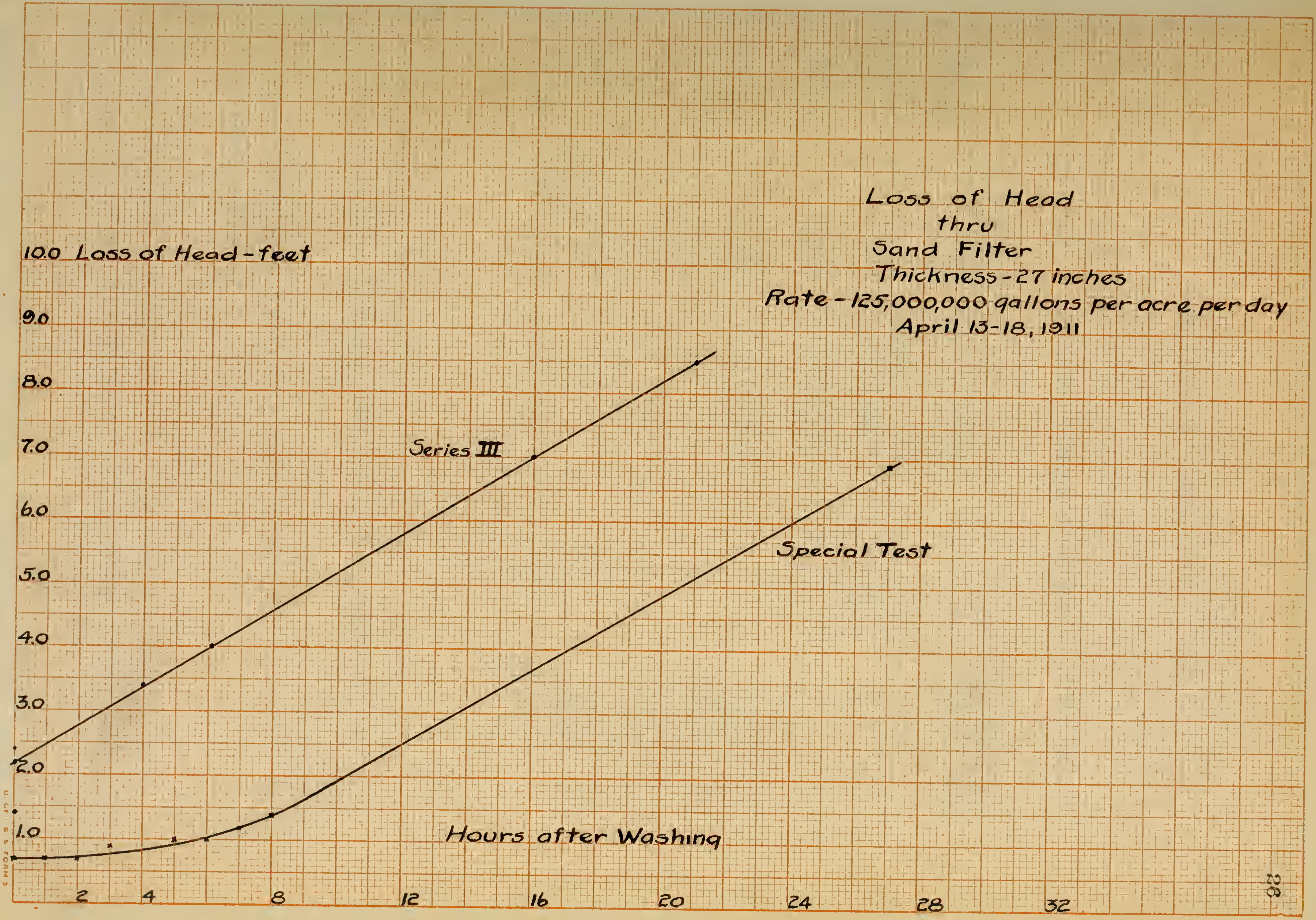
Arrangement of plant was the same as in Series III.

Filter was washed vigorously with air and water April 19th, and allowed to drain. Test was begun April 21st at 8:20 A.M. Rate of filtration was 125,000,000 gallons per acre per day.

Dissolved oxygen-parts per million		Iron-parts per million	
Well water	Above filter	Influent	Effluent
2.0	9.0	2.4	0.2
3.0	9.0	2.2	0.2

Hours after beginning of test.	Loss of head-feet.
0.0	0.7
1.0	0.7
2.0	0.7
3.0	0.9
5.0	1.0
6.0	1.0
7.0	1.2
8.0	1.4
27.0	6.9

Between the fifth and seventh hours the rate was reduced somewhat because of air in the outlet from the controller tank.


Loss of Head
thru
Sand Filter
Thickness - 27 inches
Rate - 125,000,000 gallons per acre per day
April 13-18, 1911
10.0 Loss of Head - feet
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Series III
Special Test
Hours after Washing
2
4
8
12
16
20
24
28
32

Loss of Head through Underdrains.

Area of filter -- 8 1/3 sq. ft.

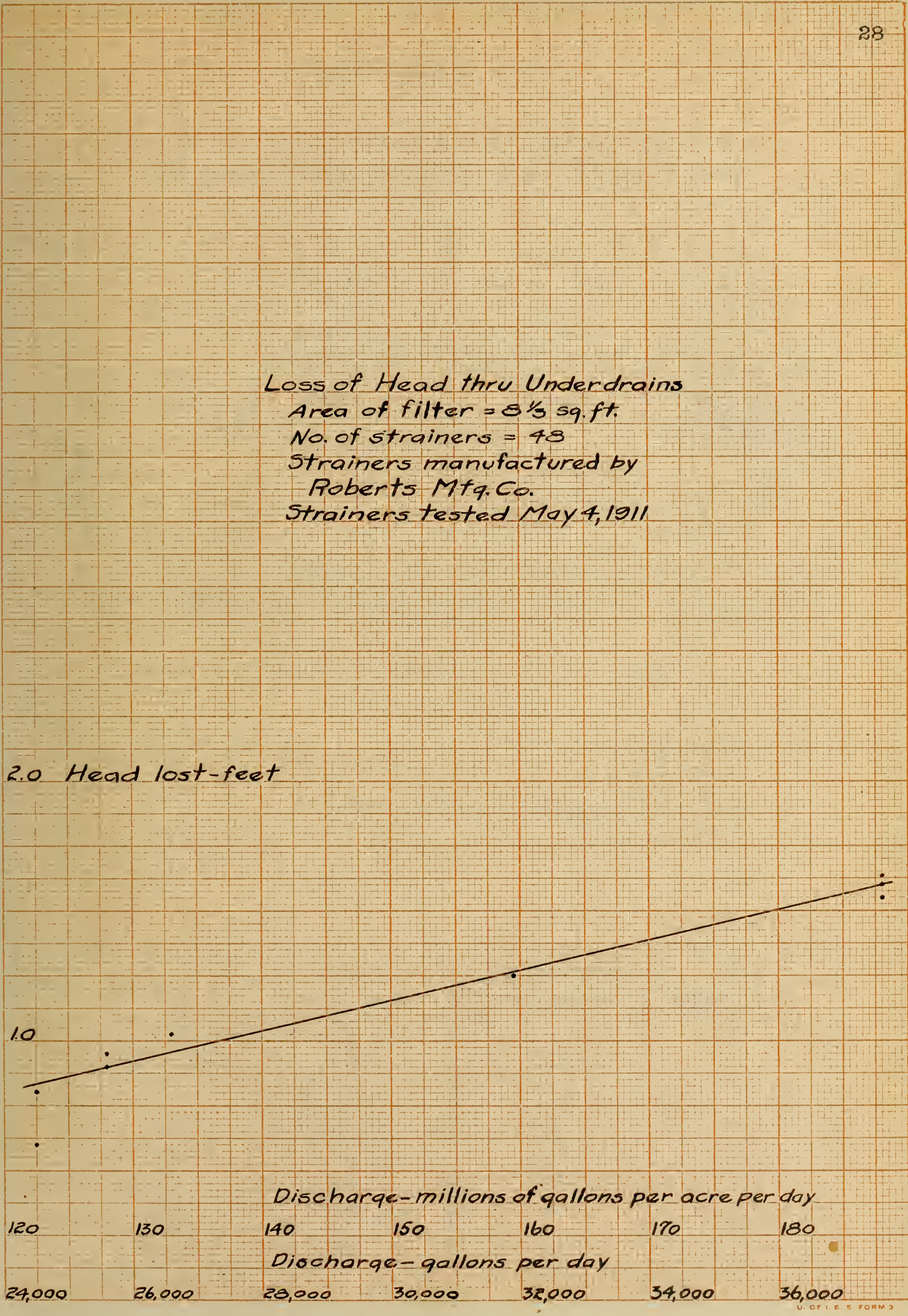
Strainers -- 48 Roberts Manufacturing Co. strainers.

Discharge			Lost Head ft.
Head on Orifice ft.	Cu. ft. per sec.	Gallons per day	
0.145	0.038	24,500	0.6
"	"	"	0.8
0.16	0.040	25,600	0.9
"	"	"	0.95
0.17	0.0413	26,600	1.03
"	"	"	1.04
"	"	"	1.05
0.245	0.0495	31,900	1.25
"	"	"	1.25
0.34	0.0583	37,600	1.55
"	"	"	1.60
"	"	"	1.64

One strainer was unscrewed and examined, and was found to be partially clogged with fine sand grains and iron.

Readings of lost head were taken at intervals of from two to three minutes.

The discharge was measured by a submerged orifice 1 1/2 inches by 2 inches, assuming a coefficient of discharge of 0.60.


Loss of Head thru Underdrains
Area of filter = 8 1/3 sq. ft.
No. of strainers = 48
Strainers manufactured by
Roberts Mfg. Co.
Strainers tested May 4, 1911
2.0 Head lost-feet
1.0
Discharge-millions of gallons per acre per day
120 130 140 150 160 170 180
Discharge-gallons per day
24,000 26,000 28,000 30,000 32,000 34,000 36,000

Miscellaneous Tests

Test of Water by Allowing it to Stand in Bottles

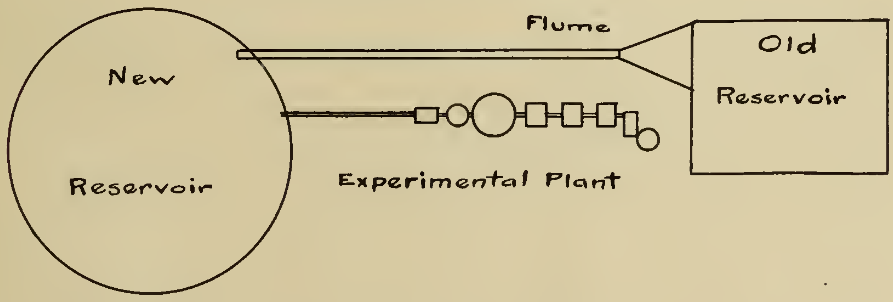
Two-liter bottles filled at 11:00 A.M. April 15, 1911

Date	From Controller Tank Iron = 0.0+ Dissolved O = 2.0	From Above Sand in Filter Iron = 1.6 Dissolved O = 9.0	From Top of Well Pipe Iron = 1.6 Dissolved O = 7.0
April 16, 1911 11:00 A.M.	Clear	Turbid	Clear
" " 2:00 P.M.	"	"	Turbid
April. 17.	"	"	"
April 18	"	"	"
April 19 9:00 A.M.	"	Nearly Clear	Nearly Clear
April 20 9:00 A.M.	"	Clear	Clear

As the water cleared in the cases of the last two columns, a brown sediment was formed on the bottoms of the bottles. No sediment appeared in the first case within a month's time.

Dissolved Oxygen in Water in Reservoirs

Parts per million



Date	Old Reservoir	End of Flume from Old Reservoir	New Reservoir
March 25, 1911	5.5	—	7.0
April 1, 1911	4.0	—	—
" 1	1.1	—	—
" 3	4.1	—	—
" 8	5.4	5.2	—
" 8	—	4.0	—
" 10	4.0	5.4	—
" 15	4.0	—	—
" 17	4.5	—	6.0
" 18	4.0	—	—

Effect of Allowing Filter to Stand Idle.

April 22nd	11:15 A.M. Loss of head = 6.9 feet.
	Water shut off and filter allowed to drain.
" 25th	10:45 A.M. Filter started up without washing
	Loss of head = 1.2 feet.
	1:30 P.M. Loss of head = 1.9 feet.
" 26th	1:15 P.M. Loss of head = 9.0 feet.
	Water shut off and filter allowed to drain.
" 29th	2:00 P.M. Filter started up. Loss of head was 3.0 feet.

Discussion of Results.

The amount of oxygen necessary to oxidize the iron in this water from a ferrous to a ferric state may be calculated as follows:

$$2\ FeO + O = Fe_2O_3$$

Atomic weight of Fe = 55.9
" " " O = 16

16 parts of oxygen will change 111.8 parts of iron from a ferrous to a ferric condition, or 0.28 parts per million of oxygen will oxidize two parts per million of iron. For this action to take place a certain amount of time and probably a small excess of oxygen are necessary. Agitation will hurry the action along. This was shown by the samples of water collected in bottles. The sample of water direct from the well containing seven parts per million of dissolved oxygen remained clear for some time, while another sample of the same water collected after running through a baffled trough was turbid when collected. The water in the old reservoir is always turbid, though the water contains only about four or five parts per million of dissolved oxygen.

After passing through the filter nearly all the dissolved oxygen in the water was found to have been used and only about one or two parts per million of dissolved oxygen was left in the effluent. As crenothrix needs a great deal of oxygen for its growth, it is believed that most of the dissolved oxygen is used by this organism.

This theory is borne out by the fact that when the filter was first used by Mr. Stromquist only one or two parts per million of dissolved oxygen were consumed in the filter. After the first three days of operation of the filter only one or two parts per million of dissolved oxygen were left in the effluent. As no test indicates that there was at any time not enough dissolved oxygen in the water for filtration, it seems probable that two or three parts per million of dissolved oxygen would be enough to oxidize the iron. This smaller amount of dissolved oxygen might also decrease the growth of crenothrix and thus be a benefit. It will be noticed that in Series III, with practical saturation of the water with dissolved oxygen, the time between washings was very short.

Washing the sand with bleaching powder improved the effluent and reduced the initial loss of head, but the filter was not restored to its original condition. However, the filter was washed with bleach only after a long period of operation, and it may be too much to expect that application of the disinfectant for a few minutes would be sufficient to destroy the growth of weeks. It is probable that a more frequent use of bleach would give satisfactory results. It seems to the writers that all the other features of an iron removal plant for this water are of little importance in comparison with the preventing or keeping in check of the growth of crenothrix in the filter.

The effect of allowing the filter to drain and

stand idle for several days is interesting because of the many breaks in the tests for this thesis. Several tests were made with the purpose of determining the effects of resting the filter and they showed that there is a great decrease in the loss of head. An examination of the sand in the filter shows that each grain becomes coated with a jelly like film. It is probable that this material fills up the voids and causes the loss of head in the filter. When the filter is drained and allowed to stand for several days this jelly like matter dries up. This drying out explains the low loss of head in the special run after the third series.

The test of the underdrains gave a much higher loss of head than was expected. The filter had been used for several tests without washing just before the underdrains were tested, so these results are probably for worse conditions than would be likely to occur in practice. It is interesting to note, however, that the loss of head through the underdrains may be quite large. Laboratory tests made by Mr. G. C. Habermeyer indicate that the loss of head for clean strainers would have been only 0.2 ft. with a rate of 125,000,000 gallons per acre per day, and with the strainers spaced as in the experimental filter.

The tests for the effect of the baffled trough were ineffective on account of the large amount of dissolved oxygen found in the well water at the time the tests were in operation.

The value of the different series of tests of the

filter is probably very small. The first series shows that the velocity of wash water available at this plant was not sufficient to allow of the filter being washed efficiently with water alone. On account of the many breaks in Series II (due to failures of the well and to lack of opportunity to visit the filter every day) this series does not give much definite information. Series III was rendered of small value because of the large amount of dissolved oxygen in the well water. This dissolved oxygen was due, as before noted, to the operation of the well pump at that time.

Conclusions.

After studying Mr. Stromquist's report and working with the experimental plant, the writers have reached the following conclusions:-

1. That two or three parts per million of dissolved oxygen in the water will be sufficient to precipitate the iron, if sufficient time and agitation are provided.

2. That a sand filter containing sand not much larger than that used in the experimental plant and with a depth of filtering material of twenty inches will remove all the iron from the water (the water filling the conditions of No. 1) when the sand in the filter is clean.

3. That the experiments already made do not give sufficient data to show that the sand in the filter can be kept clean of crenothrix for any length of time.

Suggestions for Further Experiments.

In regard to further experimentation the writers would like to make the following suggestions:-

1. Filtering water from the old reservoir, lifting the water to the filter with a centrifugal pump.

2. The determination of the effect of different disinfectants; effect of allowing disinfectant to stand in filter for some time before using air and wash water. Determination of the effect of treating water continuously with bleach before the water flows onto the filter. Determination of the effect of treating the water flowing onto the filter with bleach for a short length of time each day.

3. Continuous operation of the filter for several months to determine whether efficiency of filter would decrease with age, and whether any decrease could be prevented by the use of disinfectants.

4. Determination of the feasibility of using larger sized filtering material.

References.

Hazen, Allen -- Filtration of Public Water Supplies, John Wiley & Sons, New York. 1907 3rd Edition.

Palmer, Arthur William -- Chemical Survey of the Waters of Illinois. Report for the years 1897-1902. University of Illinois.

Stromquist, William Gottfrid -- Report to Champaign and Urbana Water Company, October 1910.

Weston, Robert Spurr -- The Purification of Ground Waters Containing Iron and Manganese. Transactions, American Society of Civil Engineers. Volume LXIV. September 1909, page 112.